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REAL TIME MEASURES OF EFFECTIVENESS (MOE) FOR ATMS

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UDOT RESEARCH & DEVELOPMENT REPORT ABSTRACT

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16.Abstract

Traffic congestion slows traffic movement, increases vehicular emissions, and pollutes the environment. State Departments of Transportation (DOTs) and local municipalities cannot keep current with the demands of growing traffic. Building new highways is not an option due to escalating construction costs, insufficient funds, and right-of-way constraints. Intelligent Transportation Systems (ITS), such as Advanced Traffic Management Systems (ATMS), promote safe and efficient use of existing transportation facilities.

ITS applications and their respective sensors and detectors provide valuable data regarding transportation systems characteristics and performance (1). The data is typically used to carry out particular ITS functions, such as traffic signal control, traveler information services, and incident management.

ITSs are expanding their operations in major urban areas and data collection is becoming more comprehensive. If ITS data is saved and made accessible it can be used for many additional purposes. For example, ITS-derived performance measures describing traffic throughput, delay, and variability could potentially be used in transportation planning, research, and other areas. Traffic management operators are currently considering the development of an automated ITS data archiving and analyzing system to improve transportation performance monitoring.

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LIST OF ACRONYMS

ADUS	Archived Data User Service
ATMS	Advanced Traffic Management Systems
DOL	Delay On-line
DOT	Department of Transportation
FHWA	Federal Highway Administration
GB	Gigabyte
HPMS	Highway Performance Monitoring System
HOV	High Occupancy Vehicles
ITS	Intelligent Transportation System
MAG	Mountainland Association of Governments
MB	Megabyte
MPO	Metropolitan Planning Organization
PeMS	Performance Measurement System
TDAD	Traffic Data Acquisition and Distribution
TMC	Traffic Management Center
TMS	Traffic Monitoring Station
TOC	Transportation Operation Center
TTI	Travel Time Index
UDOT	Utah Department of Transportation
SVG	Scalable Vector Graphics
SQL	Structured Query Language
UTL	Utah Traffic Lab
WFRC	Wasatch Front Regional Council

INTRODUCTION

Traffic congestion slows traffic movement, increases vehicular emissions, and pollutes the environment. State Departments of Transportation (DOTs) and local municipalities cannot keep current with the demands of growing traffic. Building new highways is not an option due to escalating construction costs, insufficient funds, and right-of-way constraints. Intelligent Transportation Systems (ITS), such as Advanced Traffic Management Systems (ATMS), promote safe and efficient use of existing transportation facilities.

ITS applications and their respective sensors and detectors provide valuable data regarding transportation systems characteristics and performance (1). The data is typically used to carry out particular ITS functions, such as traffic signal control, traveler information services, and incident management.

ITSs are expanding their operations in major urban areas and data collection is becoming more comprehensive. If ITS data is saved and made accessible it can be used for many additional purposes. For example, ITS-derived performance measures describing traffic throughput, delay, and variability could potentially be used in transportation planning, research, and other areas. Traffic management operators are currently considering the development of an automated ITS data archiving and analyzing system to improve transportation performance monitoring.

1.1 Problem Statement

The Utah Department of Transportation (UDOT) seeks to provide an efficient travel environment to commuters and to the traffic community in general. It has installed a comprehensive ATMS, which includes a remote-controlled traffic signal system, a ramp metering system, Variable Message Signs (VMS), High Occupancy Vehicle Lanes (HOVs), Highway Advisory Radio (HAR), complete freeway video coverage, and a traveler information system. Traffic Monitoring Stations (TMSs) are a basic component of the ATMS. They report average traffic volume, speed, and occupancy data every 20 seconds. TMSs are located on the interstate freeway system at one-half-mile intervals. Each TMS generally consists of a set of inductive loop detectors that covers each mainline and its on-ramp. The Utah Transportation Operation Center (TOC) currently uses point-based TMS data for certain operational tasks (e.g., real time travel information system and ramp metering). However, these are only some of the system's uses.

Presently, UDOT does not archive TMS data for the long-term. Raw 20-second raw TMS data is aggregated at 15-minute intervals and archived on a FTP server at TOC. One month of data storage requires 420 Megabytes (MB). The data is temporarily stored and overwritten monthly due to large data quantities. The 15-minute data is archived in a text file with about 155,000 records each day, making the archive more difficult to use.

Utah transportation communities are becoming more aware of the benefits of ITS data, and are exploring ways to use it. Agencies within UDOT (i.e. planning, traffic and safety, pavement management, ITS, TOC), as well as transportation professionals outside of the Department (i.e. Wasatch Front Regional Council (WFRC), Mountainland Association of Governments (MAG), Salt Lake City/County, and universities), hope to acquire full knowledge of transportation system performance through TMS data.

1.2 Research Scope

This study explores methods for measuring transportation performance using TMS data. This study shows how TMS data can be better used and disseminated to a variety of users. The objectives of this project include understanding nationwide practices, identifying potential performance measures derived from ITS data, and developing functional specification for a Performance Measuring System (PeMS).

The tasks for this study were:

1. Identify specific inputs, intervals, and formats for the available data to be displayed.
2. Develop algorithms for global analysis, including measurement of traffic variability and reliability.
3. Investigate technical issues concerning the development of a PeMS.
4. Identify data needs and demonstrate system benefits using a set of graphical representations.

DATA COLLECTION IN ATMS

ATMS is a computerized communications system that provides traffic surveillance and management, incident detection, and information dissemination. UDOT has installed a comprehensive ATMS. This section reviews the elements of ATMS and identifies the available data it produces. TMS data, a major ATMS data source that generates performance measures, is discussed.

2.1 ATMS Elements

Currently, UDOT's ATMS include the following elements (2):

- A TOC
- TMSs on all freeways and some arterial roadways
- Interconnected traffic signals on many arterials in addition to some ramp metering
- Closed Circuit Television (CCTV) on all freeways and some arterials
- Variable Message Signs (VMS) on all freeways and a few arterials
- Highway Advisory Radio (HAR) stations at nearly a dozen locations
- Roadway-Weather Information System (RWIS) stations at a number of locations

Figure 2.1 diagrams the relationship among these elements. TOC is the heart of ATMS. interconnects different elements of ATMS and communicates with other transportation communities. The diagram shows that TMS, CCTV and RWIS provide data inputs for other elements. After these data are processed in TOC, they are broadcast via HAR, VMS, and the Internet. Because major traffic information, such as volume, speed, and occupancy are collected by TMSs, they are a basic component of the ATMS data source. The following sections discuss the specific data inputs, intervals, and formats of the TMS data currently available.

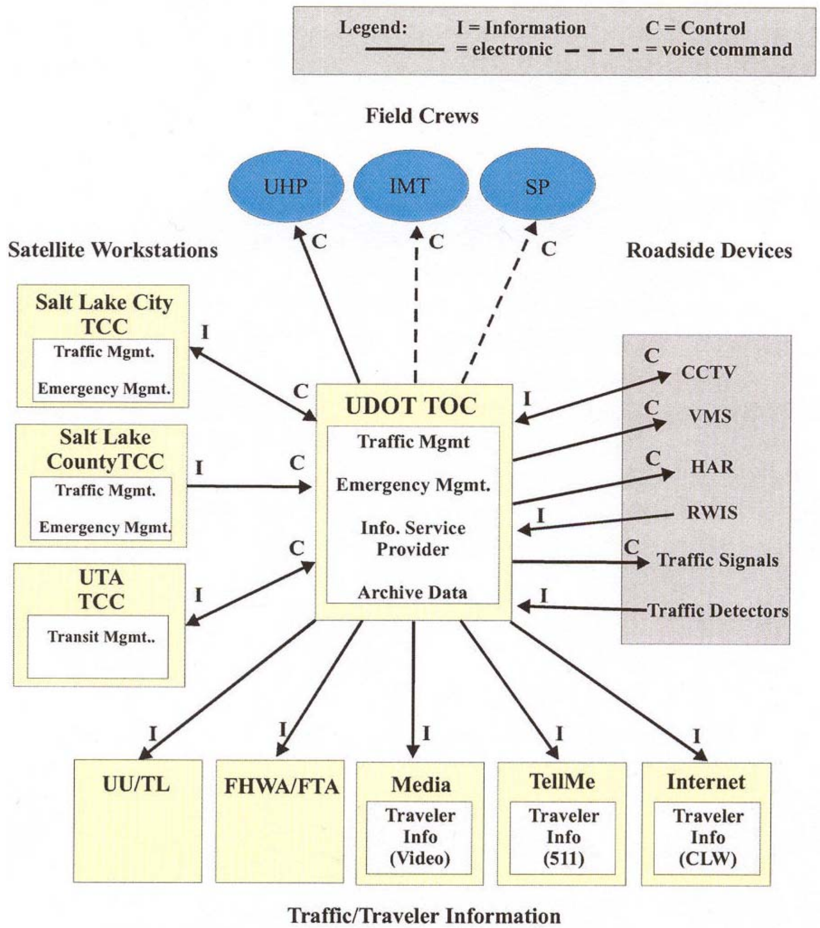

Figure 2.1 ATMS Architecture Diagram
Source: Intelligent Transportation System at the 2002 Salt Lake City Olympic Games, Iteris, Inc., August 2002.

2.2 TMS Data Collection

Currently, 641 TMSs connect to the TOC via communications links. This number will grow with TMS expansion. Almost all TMSs are located on the freeway system at approximately one-half-mile increments. A few arterials and state routes also house TMSs. Each TMS generally consists of a set of detectors. There is one detector in each mainline lane and additional detectors on the on-ramps. In almost all cases, each mainline detector consists of double inductive loops to measure volume, speed, and occupancy. The on-ramps have 23 metered detectors. The detectors generally have several loops in each lane to detect calls, clearance, and queue backup. Detectors at non-metered on-ramps have fewer loops. Figure 2.2 illustrates the layout of a TMS. TMS data include the following:

- Speed, volume, and occupancy
- Recording time
- TMS site ID
- Detector ID
- Lane ID at every TMS site
- Milepost value of each TMS site
- Location of the TMS site (including direction)

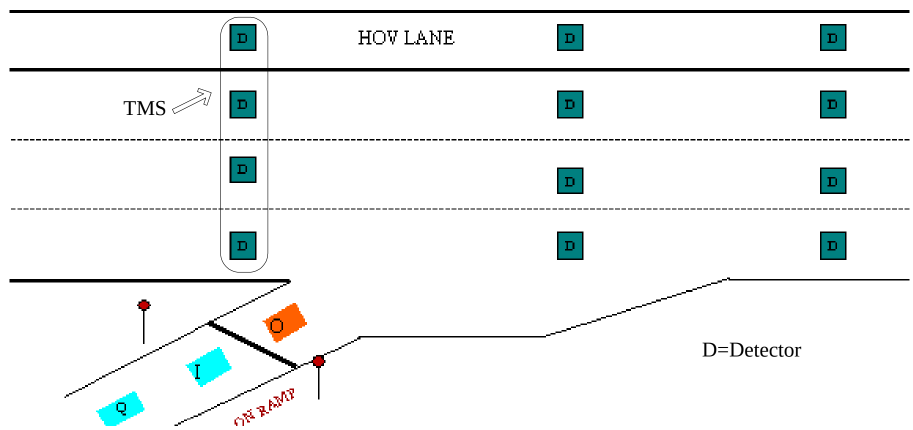

Figure 2.2 Layout of the Traffic Monitoring Station

2.3 TMS Data Storage and Processing

TMS data are collected in real time. The standard sampling period is 20 seconds. Average 20-second volumes, speeds, and occupancies continuously flow back to TOC through CommuterLink fiber-optic communications. TOC uses the data to perform real time traffic management and traveler information functions.

Figure 2.3 illustrates 20-second and 15-minute TMS data that are received and stored according to their uses. Tables 2.1 and 2.2 give the average volumes, speeds, and occupancies in both 20-second and 15-minute data levels. The malfunction records are coded as "–9."

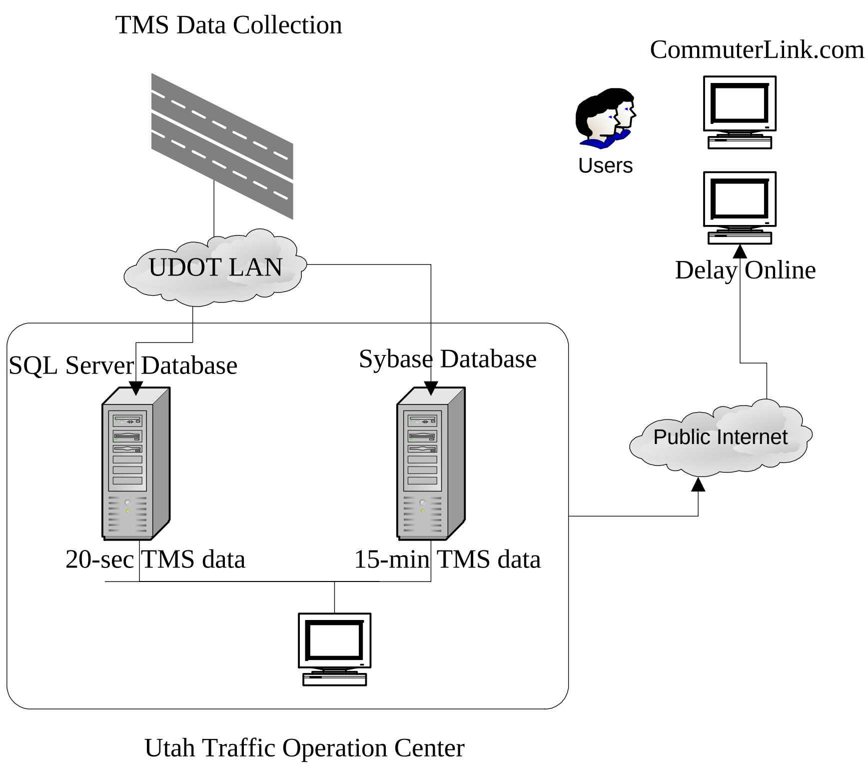

Figure 2.3 Current TMS Data Storage Process

Table 2.1 Twenty-second TMS Data Sample

Station_id	Timestamp	Volume	Speed	Occupancy
1	2003-05-21 15:48:40.000	-9	-9	-9
2	2003-05-21 15:48:40.000	33	59	11
4	2003-05-21 15:48:40.000	23	66	6
6	2003-05-21 15:48:40.000	18	63	5
9	2003-05-21 15:48:40.000	16	67	4
11	2003-05-21 15:48:40.000	9	67	3
13	2003-05-21 15:48:40.000	14	71	3
14	2003-05-21 15:48:40.000	18	69	5
15	2003-05-21 15:48:40.000	19	71	4
16	2003-05-21 15:48:40.000	15	72	4
17	2003-05-21 15:48:40.000	10	60	4
20	2003-05-21 15:48:40.000	12	62	3

Table 2.2 Fifteen-minute TMS Data Sample

DetectorID	StationID	SampleStart	Dir&Lane	Mile_Post	Station_Length	Avg_Speed	Avg_Occupancy	TotalVolume	LocationText
1263	1	Feb 9 2003 12:00AM	12	0.5	0.3	0	0	0	Interstate 215 East Southbound @ Foothill
1264	1	Feb 9 2003 12:00AM	13	0.5	0.3	0	0	0	Interstate 215 East Southbound @ Foothill
1067	2	Feb 9 2003 12:00AM	10	1.3	0.6	-9	-9	-9	Interstate 215 East Southbound @ Interstate 80 Split
1068	2	Feb 9 2003 12:00AM	11	1.3	0.6	-9	-9	-9	Interstate 215 East Southbound @ Interstate 80 Split
1069	2	Feb 9 2003 12:00AM	12	1.3	0.6	-9	-9	-9	Interstate 215 East Southbound @ Interstate 80 Split
1058	4	Feb 9 2003 12:00AM	10	1.9	0.3	69	0	23	Interstate 215 East Southbound @ 3300 South
1059.00	4.00	Feb 9 2003 12:00AM	11	1.9	0.3	65	1	78	Interstate 215 East Southbound @ 3300 South

A “buffer” in the TOC computer stores 20-second real time data. The data is then fed to CommuterLink, which provides real time traffic speed information over the Internet. It uses various colors to display speeds in different ranges. The website (http://commuterlink.utah.gov) shows the functions of CommuterLink.

The Delay On-Line (DOL) software developed by Martin Knopp, a UDOT employee, also receives 20-second data. The software displays, analyzes, and archives TMS data on Utah’s freeway system. It has a wide variety of derived performance measures focusing on traffic delay.

TMS data are aggregated at 15-minute intervals as ASCII-CSV files on a Sybase database server. The Utah Traffic Lab (UTL) began to download 15-minute TMS data in February 2002. Data from previous months was placed on back-up CDs.

DEVELOPMENT OF PERFORMANCE MEASURES

This chapter summarizes the performance measures that can be generated from TMS data. A set of models evaluates transportation systems based on the site-specific measurements of volume, speed, and occupancy.

3.1 Available Performance Measures

Table 3.1 lists performance measures that can be derived from archived TMS data (3). Spatial characteristics of performance measures are specified as point, link, corridor, and system. Point measures include traffic information, such as volume, speed, and occupancy for each individual detector and station. Link-based measurements can be taken either by lane or by segment, which combines several lanes in a road section. Performance measures such as VMT, VHT, travel time, and delay describe transportation system mobility at the corridor or system level. Each measurement taken at different spatial levels, such as at specific points or along corridor systems, is measured according to corresponding time levels ranging from 20 seconds to one year.

Table 3.1 Performance Measures

Measure Level	Measure Type	Performance Measures
Point Measures	Detector Station	Speed Volume Occupancy
Link-Based Measures	By Lane Road Segment	Speed Volume Travel time Delay
Corridor or System Measures	By Lane Road	Travel Time Delay Vehicle Miles Traveled (VMT) Vehicle Hours Traveled (VHT)

3.2 Performance Measures Modeling

There are two ways to obtain performance measures. The first is to aggregate and summarize original data to calculate measures such as volume, speed, and occupancy. The second is to derive measures, such as travel time, delay, VHT, and VMT, from existing data. Figure 3.1 shows the process of calculating performance measures. The following part of this section describes each measure individually and defines a set of algorithms to compute these measures. Some specific measures, such as Travel Time Index (TTI), traffic time variability, and reliability are also included.

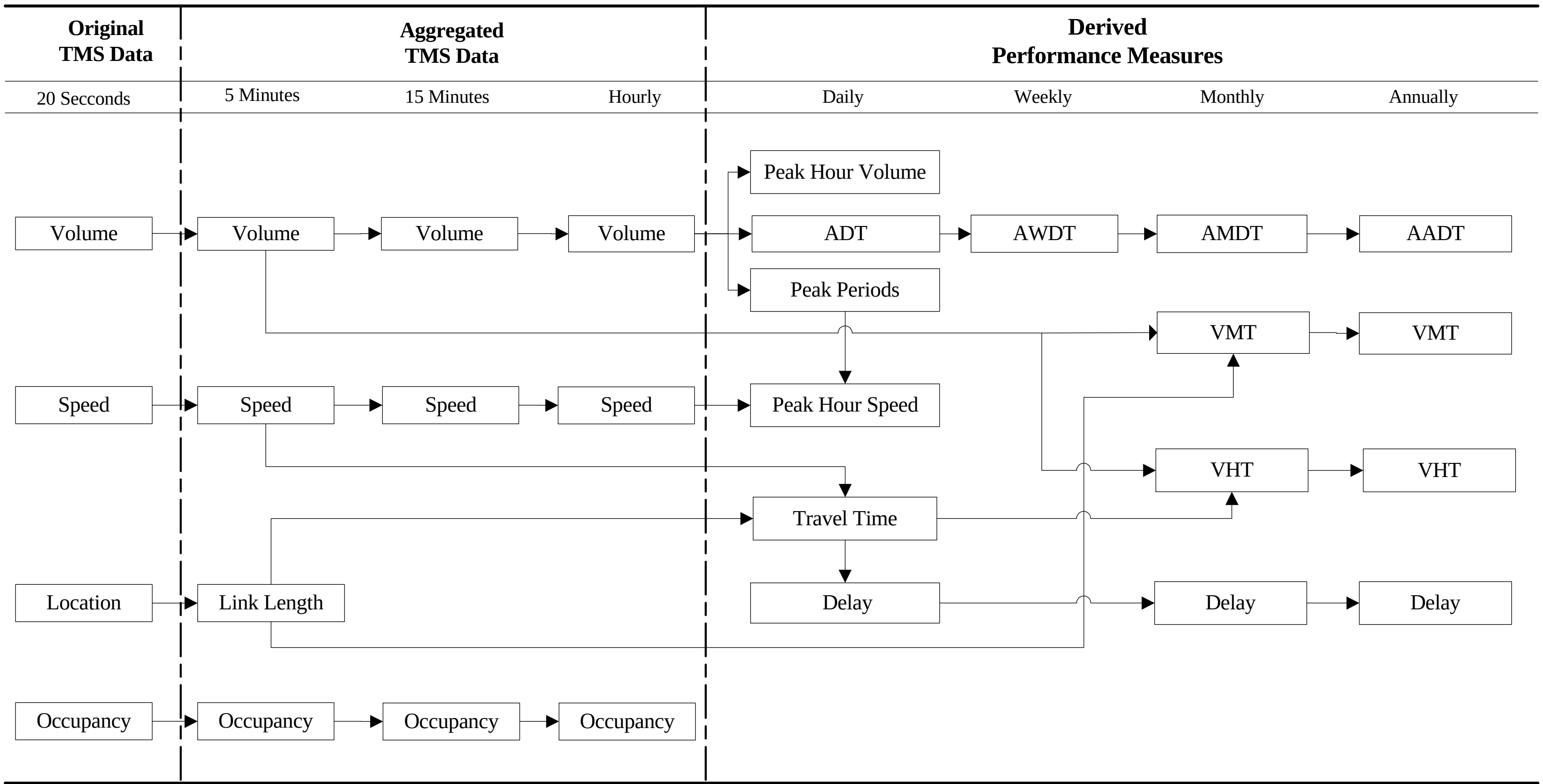

Figure 3.1 Data Flow of Performance Measures Calculation

3.2.1 Volume, Speed, and Occupancy

TMS outputs the averages of 20-second volume, speed, and occupancy data. Occupancy is a measure that describes traffic density. It is often used for short-term traffic pattern analysis. Volume and speed are the most commonly used traffic characteristics. They are measured at intervals varying from 20 seconds to one year depending on the anticipated use of the data. The data at different time intervals can be obtained by aggregating available 20-second data. Computing traffic volumes for Average Annual Daily Traffic (AADT), Average Daily Traffic (ADT), and Peak Hour Volume (PHV), also involves aggregating and averaging data.

Weighting factors should be considered in obtaining the average speed at a particular point in all lanes because original TMS data is collected by lane. Weighting factors are based on the amount of traffic volume in each lane. The lane with higher traffic volume has a heavier weight. The average speed at a specific site, based on lane-specific data, is calculated in Equation 3.1.

$$V^i = \sum_{m=1}^{n} (F_{Dm}^i V_{Dm}^i) / \sum_{m=1}^{n} F_{Dm}^i \qquad \text{Equation 3.1}$$

Where:

V^i = Weighted average speed at the *ith* TMS site for the specified period.

V_{Dm}^i = Average speed at the *mth* detector of the *ith* TMS site for the specified period.

F_{Dm}^i = Total volume at the *mth* detector of the *ith* TMS site for the specified period.

n = Number of detectors at the *ith* TMS site.

When hourly speed or peak period speed is computed, the weighting process should adjust the result. The weight is the ratio of the total volume in time of *t* to the total volume in time of *T*, as shown in Equation 3.2.

$$V_T^i = \sum_{k=1}^{n} (F_{tk}^i V_{tk}^i) / \sum_{k=1}^{n} F_{tk}^i \qquad \text{Equation 3.2}$$

Where:

V_T^i = Weighted average speed at the *ith* TMS site for the specified period (*T*)

V_{tk}^i = Average speed at the *ith* TMS site for the specified period (*t*)

F_{tk}^i = Total volume at the *ith* TMS site for the specified period (*t*)

n = the number of *t* intervals included in the *T*

$$T = \sum_{n=1}^{n} t$$

3.2.2 Travel Time

Travel time is how long it takes to travel along a particular segment of a corridor or length of a road. Travel time can be computed using the average speed of travel on a segment and the distance between two points. The stability or variability of travel time determines a transportation system's service quality.

Travel time on a particular link is computed precisely with real time speed when vehicles are traveling at a particular speed. An average five-minute speed is typically used to estimate travel time. Travel time $T_i(t)$ at time *(t)* over the *ith* segment is computed as follows:

$$T_i(t) = l_i / V_i(t)$$

Where:

> $V_i(t)$ = the average speed in a five-minute interval at the *ith* TMS at time (*t)* when vehicles travel over the *ith* segment.
>
> l_i = the length of the *ith* segment holding the *ith* TMS, which can be derived from adjacent TMS locations marked by mileposts.

Assuming $x_1, x_2, ... x_n$ as locations of *n* TMSs on a directional roadway, l_i can be measured as follows:

$$l_i = (x_{i+1} - x_{i-1})/2 \qquad \text{Equation 3.3}$$

The length of the first and last segments are represented by:

$$l_1 = (x_2 - x_1), \qquad l_n = (x_n - x_{n-1})$$

As shown in Equation 3.4, the total travel time of T for an entire or specific section of a route is obtained by aggregating travel times over the set of links constituting the route.

$$T = \sum l_i / V_i(t) \qquad \text{Equation 3.4}$$

3.2.3 Delay

Delay is the difference between the actual travel time and the travel time obtained by assuming vehicles are traveling at free-flow speed on the section being studied (4). Delay $D_i(t)$ on a link during a five-minute period can be computed as follows.

$$D_i(t) = l_i \times F_i(t) \times [1/V_i(t) - 1/f_i]$$

Where, $F_i(t)$ is the total volume at the *ith* TMS site for the specified period *(t)*, f_i is the free-flow speed at the *ith* segment. Equation 3.5 gives a summation of travel time delays over a set of individual links. It represents the total delay on some routes or within a freeway system.

$$D = \sum l_i \times F_i(t) \times [1/V_i(t) - 1/f_i] \qquad \text{Equation 3.5}$$

3.2.4 VHT and VMT

VHT and VMT describe the efficiency and productivity of a transportation system. VHT is a measurement of the total hours traveled by all vehicles on specific routes or links during a given time period. VMT is the number of vehicle-miles they have traveled in a given amount of time.

The following equations can be used to compute VMT and VHT for each link using average five-minute traffic data.

$$VMT_i = l_i \times F_i, \quad VHT_i = l_i \times F_i / V_i$$

VMT and VHT can be figured over any set of links (e.g., one corridor or the whole freeway system) and for any time intervals.

3.2.5 Travel Time Index

TTI is the ratio of peak period travel time to free-flow travel time (5). A TTI of 1.3, for example, indicates that a 10-minute off-peak trip will take 13 minutes during peak traffic. A higher TTI value indicates that the system is experiencing more severe congestion. Equation 3.6 shows how TTI is calculated. TTI can measure either chosen corridors or a whole system, depending upon the range of road links aggregated.

$$TTI = \sum l_i / V_i(t) \Big/ \sum l_i / f_i \qquad \text{Equation 3.6}$$

3.2.6 Variability and Reliability

Traffic demand variation, crashes, and other irregular events cause travel reliability problems. Both variability and reliability are measured in terms of travel time. Travel time reliability describes the predictability of a trip. A high degree of variability in travel time indicates a low degree of reliability.

ITS data provides more consistent and accurate information regarding variability and reliability in traffic conditions than traditional data gathered through sampling. The available TMS data makes it possible to statistically analyze traffic variability and reliability.

Standard Deviation (SDEV) measures the distribution of a given set of numbers. It also assesses variability in travel time. The following formula shows how to determine variability based on historical travel data. A large number of past trips were recorded to obtain the necessary inputs for Equation 3.7. The variability calculated with this equation represents a specific route during a particular period, such as rush hour or off-rush hour. High standard deviation results in higher variability and more unpredictable travel time.

$$s^2 = \sum (T_i - M)^2 \Big/ n-1 \qquad \text{Equation 3.7}$$

Where:

- s = the estimate of travel time standard deviation.
- T_i = the travel time of the *ith* travel crossing a specific route.
- M = the mean travel time of a set of samples.
- n = the number of sampling travels.

Level of confidence can be used to quantify travel time reliability. Theoretically, the 95% confidence region contains 95% of the historical travel time data of a representative sample of the population. In other words, based on past trips, a traveler could obtain the suggested travel time with a 95% probability of actually arriving within the pre-planned time. For example, it takes an average of 13 minutes for a commuter to travel from Sandy to downtown Salt Lake City. However, due to congestion, the commuter has to plan on 20 minutes if he or she wants to arrive at work on schedule 95% of the time. With increased traffic demand, the 20 minutes needed would likely only guarantee an 80% possibility of on-time arrival in the future.

Figure 3.2 shows the process of calculating traffic variability and reliability. TMS data provides basic inputs for this algorithm. As described earlier, travel time can be derived from TMS speed data and location information. Users must also provide the expected number of trips, *n*. Trips should occur during the same traffic periods such as AM peak, PM peak, or off-peak for SDEV to be computed for different traffic congestion periods.

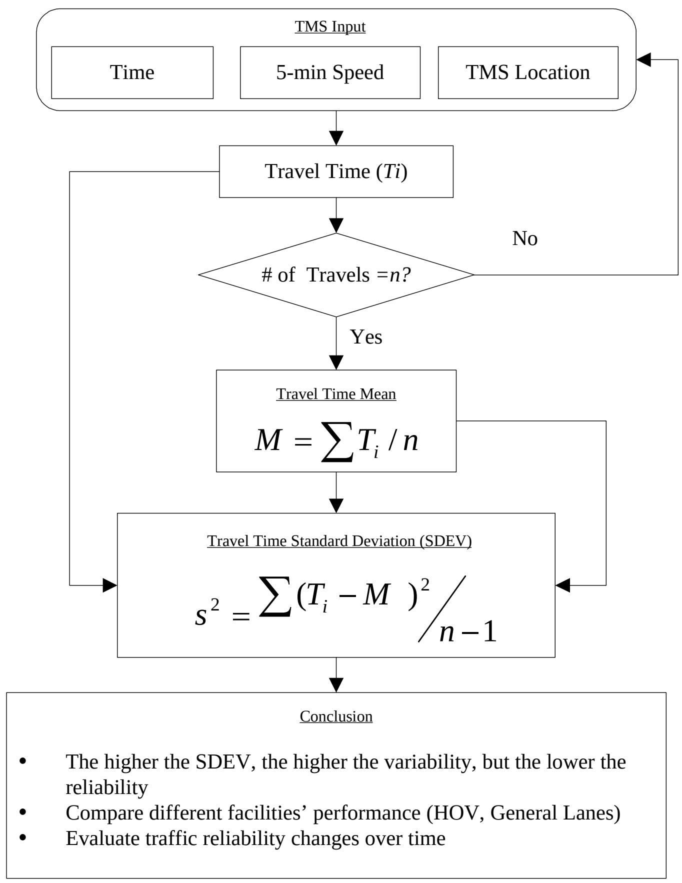

Figure 3.2 Traffic Variability and Reliability Algorithm

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PERFORMANCE MEASURING SYSTEM ARCHITECTURE

This chapter describes the architecture of an automated TMS archiving and performance measurement system. It provides guidance for archiving, analyzing, and disseminating TMS data. The system has several capabilities:

- Stores and manages large amounts of data.
- Aggregates data, derives performance measures at different spatial and temporal levels, and presents them to users in tabular and graphical formats.
- Has a user-friendly point-and-click query interface to acquire measures of interest.

The following section expands upon these features as it documents the development of a PeMS used to archive, analyze, and present TMS data. This information can guide researchers in their development of a prototype version of a TMS data utilization system.

4.1 Conceptual Architecture of the Performance Measuring System

Figure 4.1 shows the six components of the proposed TMS system data collection, data transmission interface, data aggregation and quality control, off-line data storage, database management system, and user interface.

TMSs are the primary source of archived data. They measure traffic volume, speed, and occupancy using double inductive loop detectors at hundreds of freeway locations. The system receives real time data every 20 seconds from TMSs on UDOT’s Local Area Network.

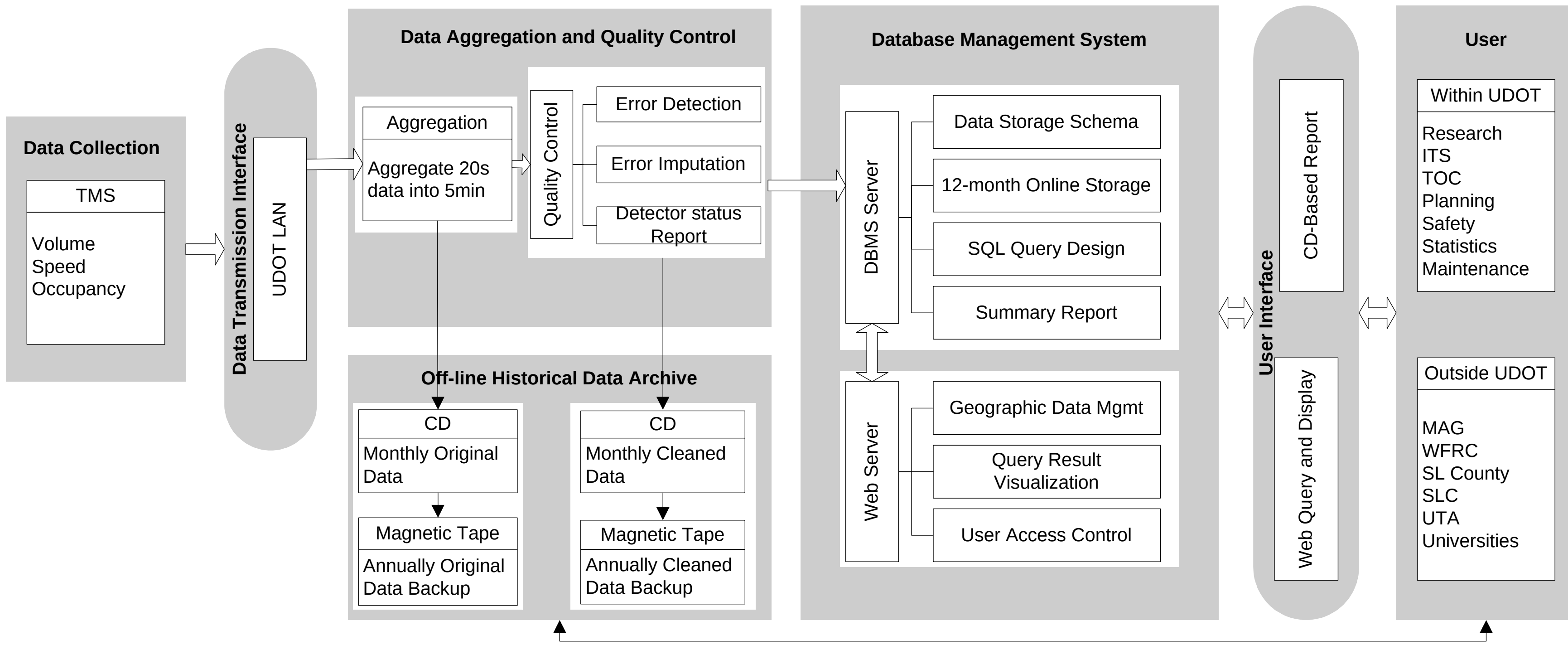

Figure 4.1 Conceptual Architecture of the Performance Measuring System

The data processing block in Figure 4.1 is comprised of data aggregation and quality control. The system can aggregate received data into a level that reduces data flow size without sacrificing user needs. Data quality control detects erroneous data, imputes missing data, and produces a detector status report to assist TMS inspection and maintenance.

The system also stores raw and processed data on and off line. Original five-minute data is always preserved permanently off-line in the historical data archive. After the data quality control procedure, processed data should also be copied off-line. Data processed in the last 12 months are kept in a database management system for on-line queries.

The archived data management system is a key subsystem for PeMS. It implements all of the functions that provide data users with different types of data products. It also includes a Database Management System (DBMS) server and a web server. Users can input queries on the web server without acquiring DBMS knowledge.

4.2 Data Aggregation

The enormous volumes of TMS data being collected require innovative storage and aggregation strategies. TMS data coming from detectors at 20-second intervals is currently aggregated at 15-minute intervals and archived as ASCII-CSV files on a FTP server. According to a previous data needs survey, users from different agencies require data at different time interval measurements, ranging from five minutes to one hour. To meet the data requirements for multiple applications 20-second raw data should be aggregated into five-minute intervals rather than the current 15-minute intervals. The archiving system should also be able to summarize five-minute data over various time periods, ranging from 15 minutes to one hour to one day. This allows the database to serve a number of different purposes, including real time point analysis, corridor congestion monitoring, and long-term planning applications.

Data aggregated at five-minute intervals is reasonably detailed at 12 data intervals per hour. The size of five-minute data is also manageable in DBMS. Table 4.1 shows the required storage sizes for different aggregation levels. For example, each day of data at five-minute periods requires approximately 33.6 megabytes (MB) of storage space. A month of the same aggregated data requires 1.0 gigabyte (GB). A full year of data requires 12.3 GB. An efficient data storage strategy is needed to control the constant flow of TMS data.

Table 4.1 Comparison of Data Size in Different Storage Levels and Times

Time \ Level	20 seconds	5 Minutes	15 Minutes	60 Minutes
Day	504 MB	33.6 MB	11.2 MB	2.8 MB
Month	15.1 GB	1.0 GB	336 MB	84 MB
Year	184.0 GB	12.3 GB	4.1 GB	1.02 GB

5.3 Data Storage

TMS data can be stored either by keeping the original 20-second data or storing aggregated data. As shown in Table 5.1, a full year of 20-second data is about 184.0 GB. It is not economical to save such a large amount of data. The previous analysis proved that five-minute data could provide a reasonable basis for future analysis. Therefore, the most cost-effective storage approach is to archive this five-minute TMS data.

As shown in Figure 5.1, raw and processed data can be stored both on and off-line.

Off-line Storage

The off-line Historical Data Archive contains raw and processed data. Original, unaltered data must always be preserved off-line for long time periods in order to preserve its integrity. Original data stored in the master archive should not be modified as the result of user-specified data requests or data manipulation. User-defined data manipulation (e.g., editing, formatting, aggregation, cleaning, or fusion of data) should only be processed from copies of the master archives. Cleaned or otherwise transformed data can co-exist with the original data in the Historical Data Archive for specific user applications. CDR and Magnetic Tape are recommended as cost-effective data storage devices for the Historical Data Archive because of their capacity, cost, and durability.

On-line Storage

Most archived data are distributed on-line through web queries. This provides flexibility for data analysis. Three types of on-line data, determined by aggregation level, are stored in DBMS: current 20-second raw data, the last 12 months of five-minute data, and hourly data from previous years. The 20-second data presents a quite comprehensive picture of data received from TMSs. It can be compared with cleaned data to verify data integrity. Five-minute data can satisfy different levels of data needs. DBMS currently does not have the capacity to store an unlimited amount of data. Long-term historical data is only stored in a 60-minute level to reduce the amount of data stored on-line. Users usually require detailed data for the most recent time periods. Therefore, this storage strategy balances data needs and DBMS limitations. The storage of long-term hourly data can also improve data analysis efficiency because it can be processed from 60-minute data instead of five-minute data.

4.3 Data Quality Control

Invalid data do not accurately represent road conditions. Therefore, completely accurate conclusions cannot be drawn from this data. Figure 4.2 shows a sample of TMS speed data at I-15 Northbound and 5800 South on February 24, 2002. This figure defines three types of data errors: suspect data, erroneous data, and missing data. Erroneous data includes unrealistic speeds, such as negative speeds and speeds beyond 100 mph. Missing data includes data gaps caused by detector malfunction or communication failures. Suspect data means that some data do not reflect the expected outcome. A comprehensive procedure of checking data quality, identifying and correcting erroneous data, and imputing missing data should be performed in the TMS data archiving system.

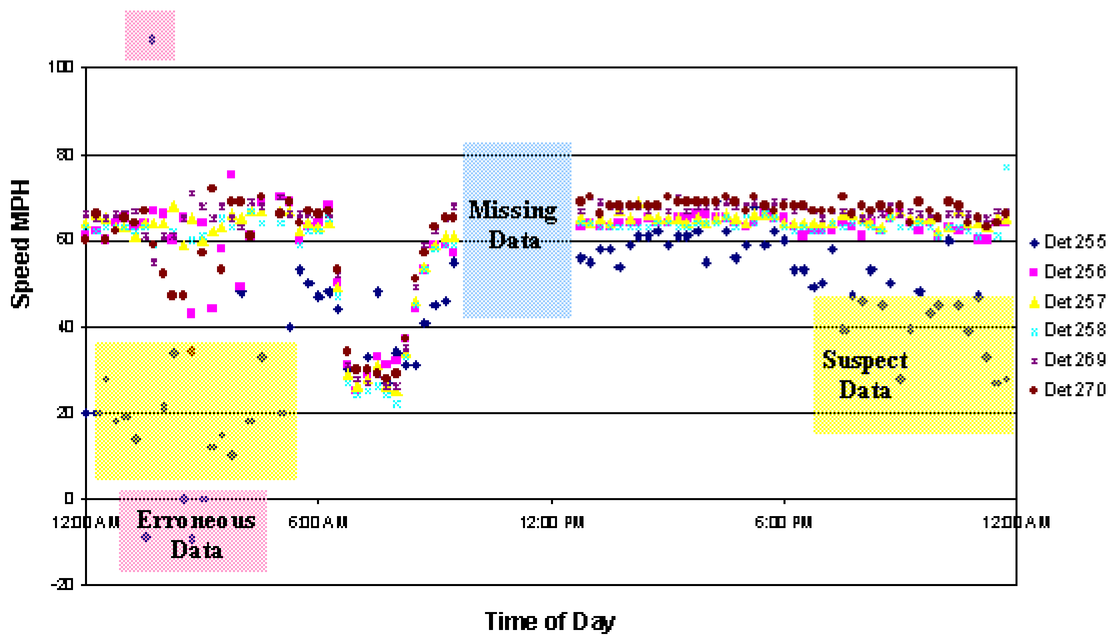

Figure 4.2 Data error types at Interstate 15 Northbound @ 5800 South

4.4 Database Management System

Choosing DBMS

The total size of on-line data stored in a DBMS is beyond 13.8 GB. Therefore, it is unlikely that medium-sized desktop applications such as Microsoft Access can effectively store and manage data.

Many large businesses and corporations use “enterprise-class” relational databases on computer workstations to manage data requiring more than about five GB. These large databases are often called “data warehouses” or “data marts.” A data warehouse is a “separate data store in which the data is stored in a format suitable for business intelligence and decision support systems, in which these systems do not interfere with the performance requirements of operational systems” (6). A data mart is a scaled-down version of a data warehouse. It typically contains between five and 15 GB of data, while a data warehouse typically contains more than 30 GB of data. Several software developers (e.g., SQL Server, Oracle, Sybase, Informix, etc.) are currently marketing products for data mart and data warehouse management. A database product supporting warehouse functions is recommended during the development of PeMS.

Conceptual Schema of Database

The conceptual schema of the database must be established using a high-level data model. Variations of multi-dimensional schemas accommodate more complex data structures and support data variations. Figure 4.3 tracks time, date, and location dimensions for TMS data. Volume, speed, and occupancy data are stored in the traffic fact table. The fact data are expected to grow as new TMS data is received. Each record in the fact table is linked to each of the date, time, and location dimensions. This links all data subjects together and allows for cross-subject queries and analysis.

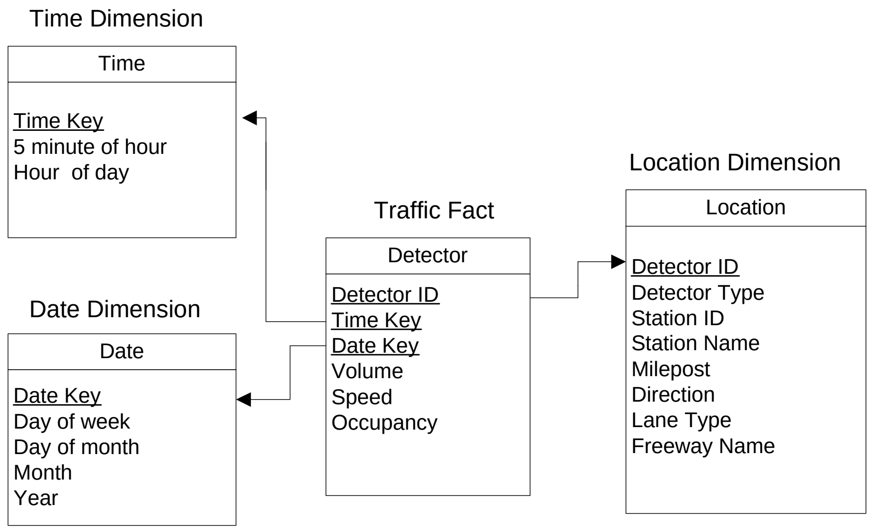

Figure 4.3 Multi-dimensional Implementation of TMS data

Time and date dimensions can be used with the traffic fact table to analyze traffic at different temporal and spatial scales. This method allows for queries such as average speed on the I-15 corridor on Friday and traffic volumes on the HOV lanes during different peak periods. Location dimension is also associated with traffic analysis at varying spatial scales. Possible queries include average volume at a certain TMS site or at a traffic bottleneck on I-15 where TMS sites frequently show the lowest speed.

4.5 User Interface

The PeMS user interface enables novice database users to perform both simple and complex data queries. The interface should be user-friendly and fairly simple to understand to accommodate novice users. Web browsers are popular and easy to use.

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PERFORMANCE MEASURING SYSTEM DEMONSTRATION

A performance measuring system was developed for demonstration purposes and is not fully functional. However, all functions of this prototype can be implemented. The TMS data information system is located on a web site that allows users to query, analyze, display, and download data. A server-based program behind this web interface processes incoming TMS data from the field and makes it available in various formats to all users or interfacing systems requiring access.

5.1 Real Time Traffic Information

TMSs transmit real time data to CommuterLink, Utah's Intelligent Transportation System. It is the primary source for real time traffic information. As shown in Figure 5.1, the prototype provides an interface to CommuterLink.

The TMS data information system recommends enhancing CommuterLink to better use comprehensive TMS data. For example, instead of simply representing traffic movement through the use of color, line width could increase and decrease according to the number of cars. TMS data can be used to identify traffic speed and compare traffic conditions in different lanes. For instance, HOV lanes can be compared to general-purpose lanes during traffic peak periods to determine their effectiveness. Figure 5.2 demonstrates traffic by lane.

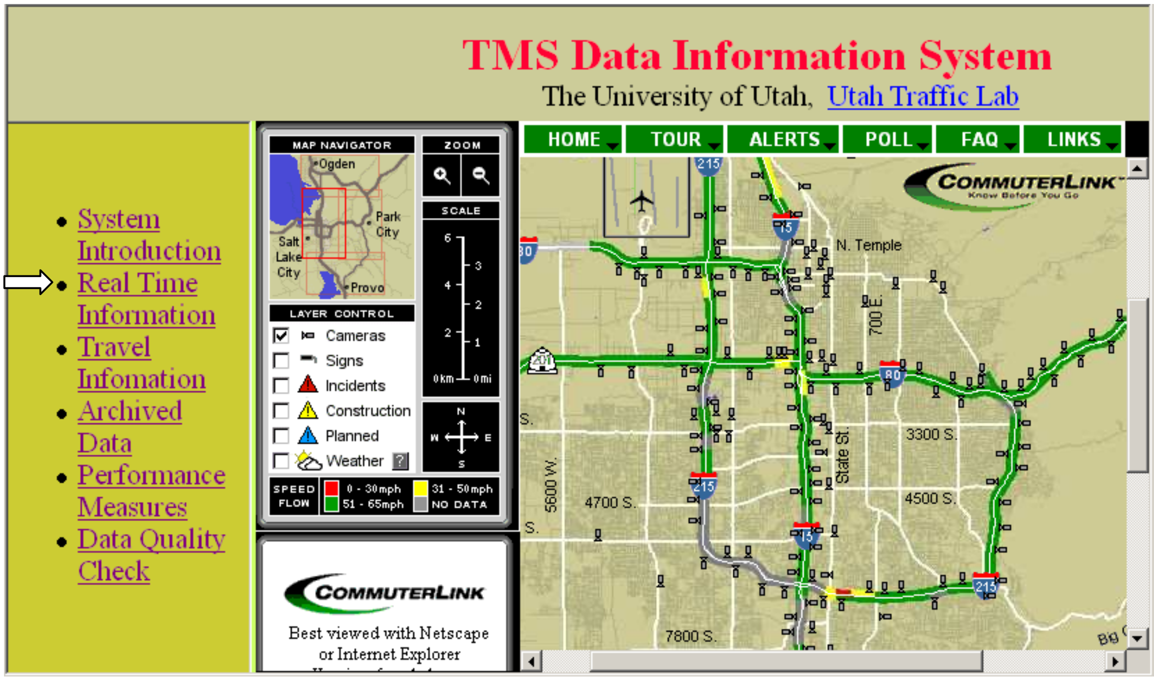


Figure 5.1 System Demonstration: Real Time Traffic Information

Figure 5.2 System Demonstration: Traffic Shown by Lane

5.2 Travel Guidance Information

Travel time varies greatly during peak hours. Estimating an accurate travel time allows travelers to budget adequate time for their trips. Based on real time TMS data, travelers can acquire current travel time predictions and optimum routes from origin to destination. Historical travel time can also be provided. The interface in Figure 5.3 shows how to use these services. Estimated travel times can vary depending on use of different facilities (i.e. HOV lanes). The interface can also help predict travel time when HOV lanes are used.

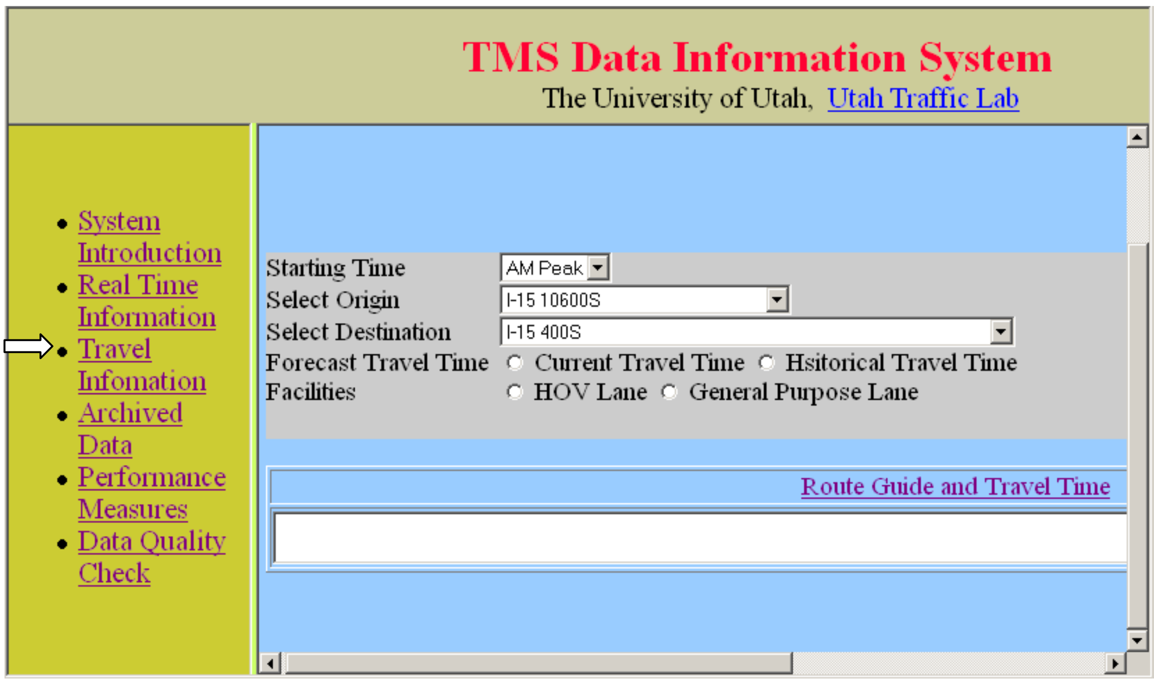


Figure 5.3 System Demonstration: Travel Guidance Information

5.3 Archived Data

One important function of the proposed system is the ability to distribute archived data through the web browser. The interface shown in Figure 5.4 allows users to query any available TMS data being stored on-line. Users may query data for specific information based on any data-element that has been collected and stored. Users may choose to download raw or processed data. They can input the following parameters through the interface to obtain data:

- Time Stamp (*time and date of dataset*)
- Data Source (*speed, volume, occupancy, length, etc.*)
- Data Granularity (Aggregation Level) (*20-second or 5minute bins*)
- Data Type (*raw data or processed data)*
- Detector location (*Station ID, Lane location, or Detector ID)*

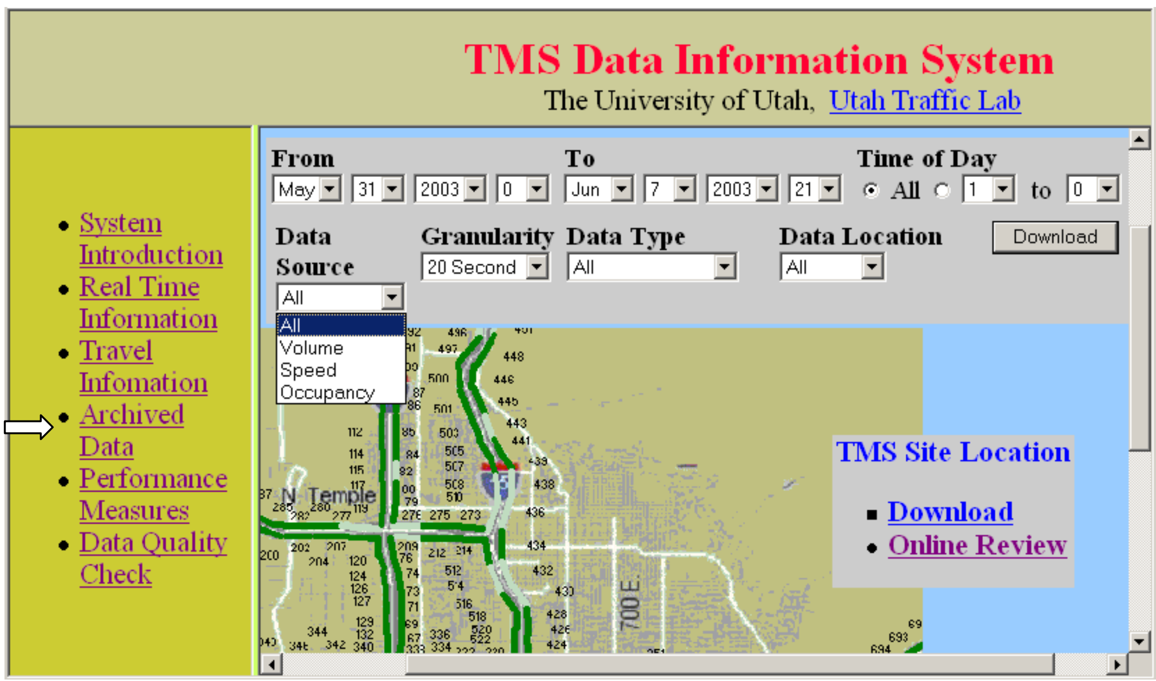


Figure 5.4 System Demonstration: Archived Data

Archived data also contains information on TMS sites, such as station and detector location, time intervals for the data collected, and the number of records for each TMS. Figure 5.5 gives an example of the “Meta data.” It shows station ID and location.

TMS Site Inforation

StationID	Records#	Locations
1	192	Interstate 215 East Southbound @ Foothill
2	288	Interstate 215 East Southbound @ Interstate 80 Split
4	288	Interstate 215 East Southbound @ 3300 South
6	288	Interstate 215 East Southbound @ 3850 South
9	288	Interstate 215 East Southbound @ 3920 South
11	288	Interstate 215 East Southbound @ 4500 South
13	288	Interstate 215 East Southbound @ 4550 South
14	288	Interstate 215 East Southbound @ 4800 South
15	288	Interstate 215 East Southbound @ 5100 South
16	288	Interstate 215 East Southbound @ 5500 South
17	288	Interstate 215 East Southbound @ 6200 South
20	288	Interstate 215 East Southbound @ 6220 South

Figure 5.5 System Demonstration: TMS Site Information

5.4 Performance Measures

Performance measures can be derived from the archived TMS data of flow and speed for each road segment, and then aggregated in terms of time and space. The major goal of this system is to report performance measures over geographical segments for different time periods. Figure 5.6 shows an interface for acquiring performance measures. Performance measures such as VMT, VHT, and delay can be selected in the "quantity" box. There are three options for performance measure's spatial coverage: point, freeway corridor, or whole system level. The interface also allows users to choose a time range, from one day to one year. Figure 5.7 shows an example of 24-hour delay analysis for the whole freeway system.

Output can be customized to different formats according to UDOT's reporting requirements. Users can also view the result on-line. The result can be graphically represented by line, point, or bar graph according to users' needs. Users may save queried data and data views within the application as a file. Formats of export files include (but are not limited to) the following:

- Comma delimited or Tab delimited ASCII text
- Excel file
- UDOT reporting format

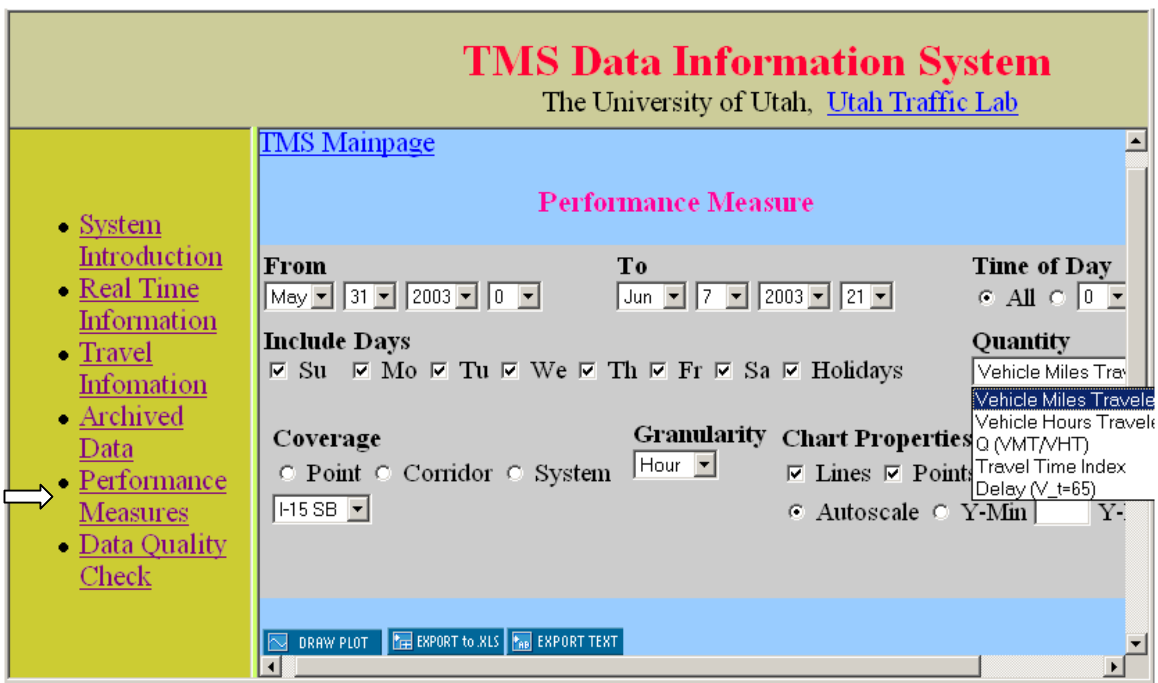


Figure 5.6 System Demonstration: Performance Measures

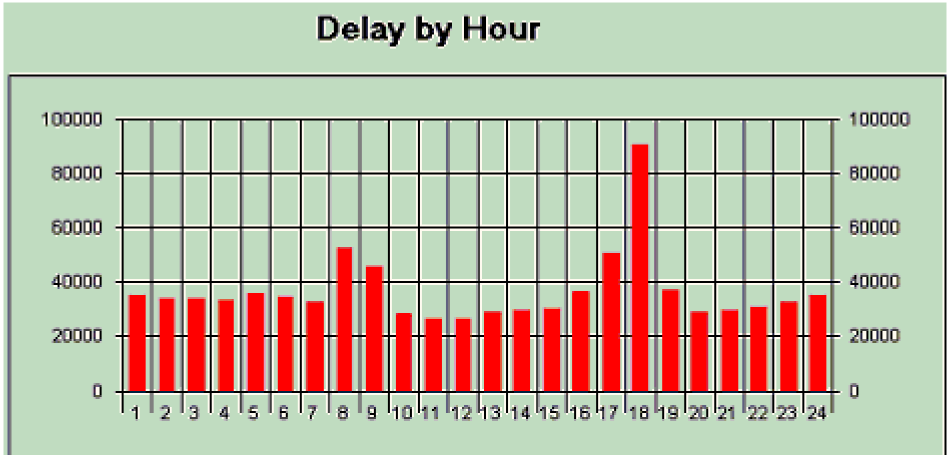
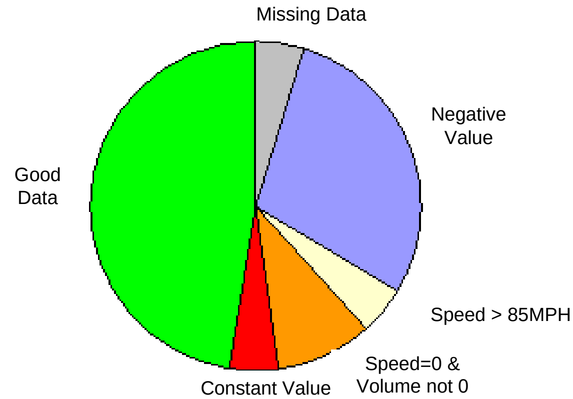


Figure 5.7 System Demonstration: Delay by Hour

5.5 Data Quality Check

The volume of archived data is growing and users are becoming more concerned with data quality. Equipment errors and malfunctions must be systematically inspected and maintenance performed. Data quality check is emphasized. A data quality report can be generated for each detector and station by day. Users can also obtain a report concerning all of the TMS data generated during a specified time period. Figure 5.8 shows a data quality report. The pie graph illustrates the percentage of data errors for each error type. The associated table describes possible causes for these errors.



Error Types	Description	Possible Causes	Percentage of Errors
Missing Data	Missing time intervals	Communication Failure Malfunction, Installation	4.8%
Negative Value	Volume & Speed = -9	Malfunction Communication Failure	28.8%
Unrealistic Value	Avg. speed > 85 MPH Speed=0 but Volume not 0	Calibration Malfunction	4.6% 9.7%
Constant Value	Constant value in a long time (constant 0 records)	Malfucntion	4.7%

Figure 5.8 System Demonstration: Data Quality Report

APPLICATIONS OF TMS DATA

ITSs continuously collect traffic data. However, users do not understand the benefits of ITS data beyond their uses in the TOC. Therefore, these data have rarely been used outside the system. This section identifies beneficial information that can be produced from archived ITS data and provides a better understanding of the necessity and advantages of archiving ITS data. The primary data types currently generated by ITSs are speed, volume, and occupancy. This chapter identifies the benefits of TMS data. It also discusses the data available and how it can be presented graphically.

6.1 Benefits of TMS Data

There are often usage similarities between ITS-generated data and data collected manually or by traditional traffic recorder stations. ITS data, however, is more extensive and detailed in temporal and spatial coverage. The general benefits of ITS data are summarized below.

6.1.1 Generating Performance Measures

Transportation policy is shifting away from large-scale, long-range capital improvements and toward better management of existing facilities. ITS-generated data can support the more intensive PeMS required to meet this new paradigm. ITS data provides an abundance of traffic facts at detailed temporal and spatial levels. The summation of this detailed data constitutes a corridor or system measure.

6.1.2 Monitoring Traffic Characteristics

Continuous ITS data allows direct measurement of traffic reliability and variability. These are important factors when studying personal travel habits and the effect of extreme events on traffic (e.g., days with very high volumes). Since the data is continuous, it removes temporal sampling bias from estimates and allows for the study of variability (21). Nearly all of the data currently collected for planning, operations, administration, and research applications is obtained through sample surveys such as short-duration traffic counts. Although attempts are made to adjust or expand the sample, the procedures are imperfect. Continuous ITS data does not require adjustments to control sample bias.

6.1.3 Improving Transportation Modeling

The detailed data needed to meet input requirements for new modeling procedures can be provided by ITS data sources. The next generation of Travel Demand Forecasting (TDF) models (e.g., TRANSIMS) and air quality models will operate at a much higher level of granularity, or level of detail, than existing models. These models require more detailed data than what is currently being collected (12).

Traditional data sources will be incapable of supporting the next generation of models. Much of the data generated by ITS is collected at the level of detail necessary to support future models. For example, TMS data is reported every 20 seconds. This level of detail will be required for the input and calibration of data used by the new models. In addition, detailed ITS data can be used as input for current traffic simulation packages such as CORSIM and VISSIM instead of the average hourly traffic data traditionally collected. This improves simulation accuracy.

Example Applications of Archived TMS Data

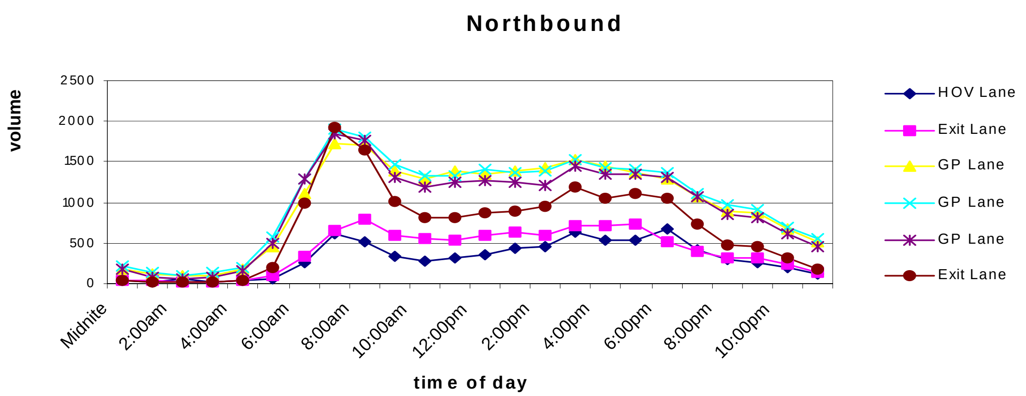
This section explains and graphically demonstrates ITS applications in other states.

6.2.1 Traffic Operation

Stakeholders in traffic operations are primarily concerned with the day-to-day operations of TMCs. Traffic management operators are interested in traffic control strategies, highway capacity analyses, incident management, and performance evaluation and monitoring. Data requirements for these analyses are often on a more disaggregate level than for transportation planning applications. Data are usually desired at aggregation levels of one, five, or 15 minutes. However, some applications such as incident detection algorithm development may require data at intervals of less than one minute. Typical applications evaluating highway capacity or ramp metering strategies may use data at the five-minute aggregation level. These applications often require data for various segments and time periods.

Example 1: Generate Traffic Profile

TMS detectors are located in each lane of roadways. Daily traffic profiles can be calculated based on these data. Figures 6.1 and 6.2 show examples of daily volume and speed profiles. This information is valuable for tracking variations in daily traffic. Profiles can be created by lane and direction. The speeds and volumes in different types of lanes, such as HOV lanes and general purpose lanes can also be compared. These two figures illustrate traffic volume and speed patterns during peak traffic periods. An examination of seasonal traffic variation can also be derived from such ITS data.



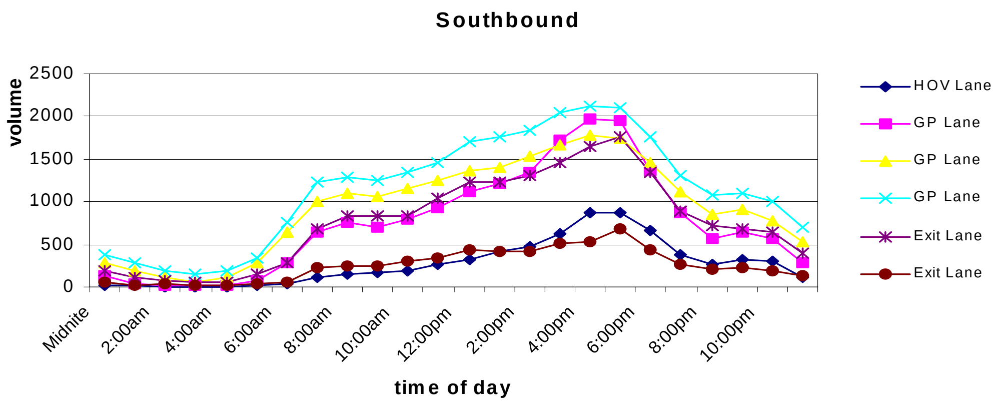


Figure 6.1 24-hour Volume Profile at a Specific Point

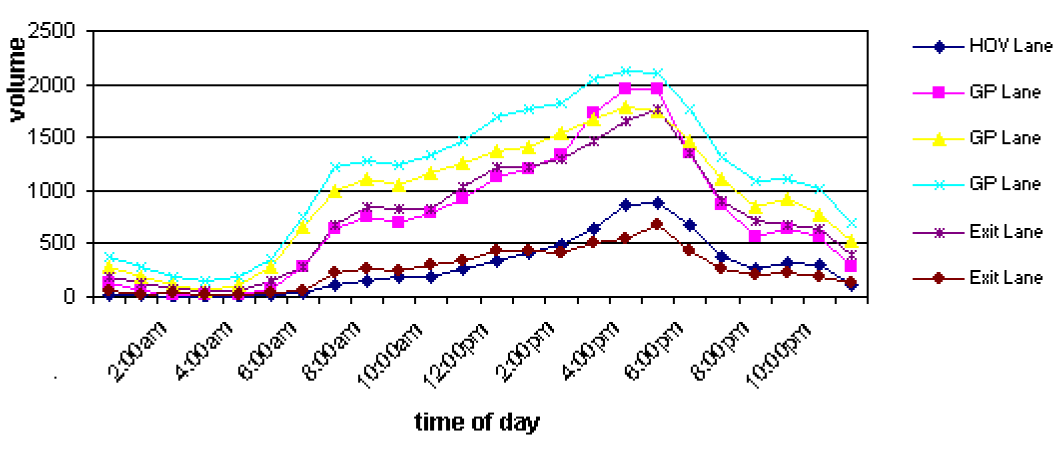


Figure 6.2 24-hour Speed Profile at a Specific Point

Example 2: Incident Analysis

Detailed TMS data provides an opportunity to examine the impacts of traffic incidents. Figures 6.3 and 6.4 illustrate the effect of an incident on surrounding traffic. Both figures show that an incident significantly reduces traffic flow rate and speed. The duration of an incident's effect can also be determined using this data.

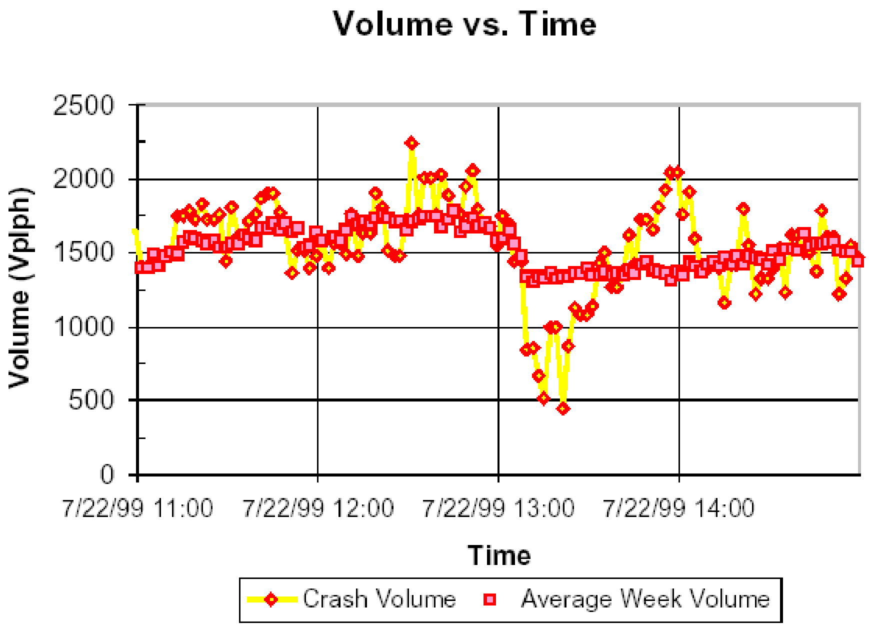


Figure 6.3 Incident Volume Profile
Source: Some of the Many Uses of Information Generated From Archived Traffic Data. Virginia Transportation Research Council, 2001.

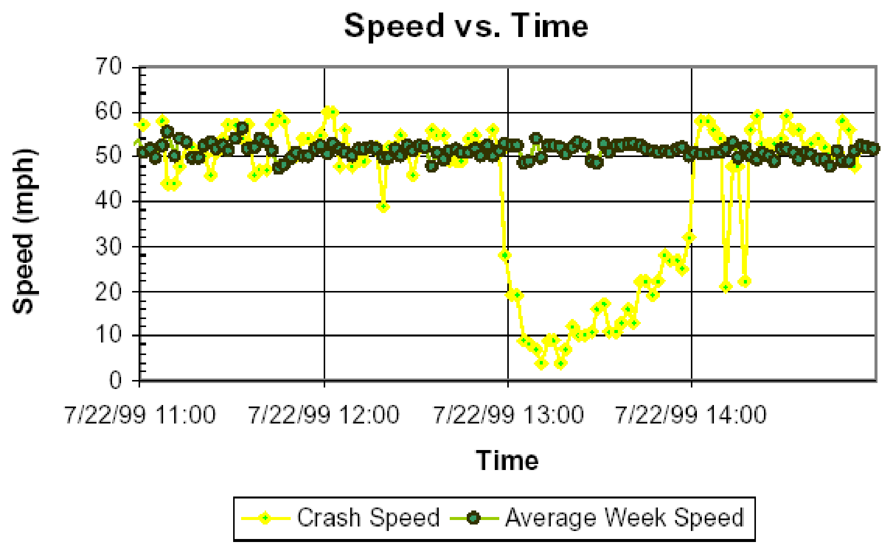


Figure 6.4 Incident Speed Profile
Source: Some of the Many Uses of Information Generated From Archived Traffic Data. Virginia Transportation Research Council, 2001.

Example 3: Ramp Metering Evaluation

Archived ITS data evaluates ramp-metering operations in PeMSs. The VHT along a specific section of a freeway system is calculated according to location and traffic detector data. Ramp metering performance is evaluated using the VHT as the delay saving estimate. In Figure 6.5, the top curve shows the actual VHT. The bottom line shows the minimum VHT if every vehicle were allowed to travel at 60 mph. The middle curve is the delay under ideal metering. Ideal metering refers to metering done at on-ramps so that the flow onto a freeway is always free flow. The difference between ideal metering and minimum VHT represents delay and time spent waiting on the ramps due to excessive demand. These measurement results can be used to determine the places where metering will create the greatest delay savings.

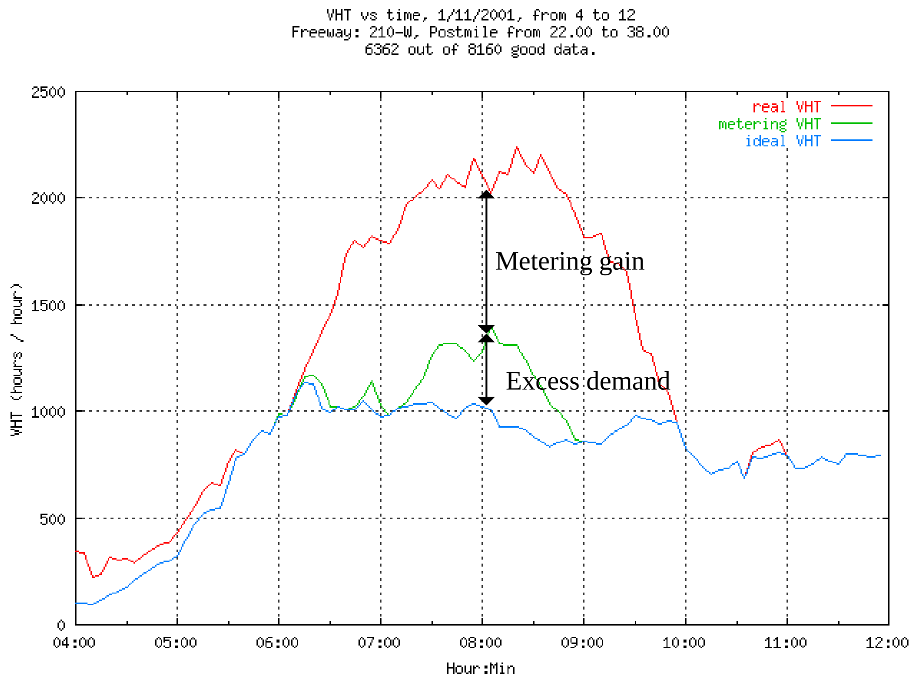


Figure 6.5 Ramp Metering Evaluation
Source: Pravin Varaiya, Freeway Performance Measurement System. California PATH, 2001.

6.2.2 Transportation Planning

While a traffic operator is interested in the real time performance of a system, a traffic planner is interested in long-term trends in traffic performance. Transportation planners commonly require traffic data for traffic demand forecasting, congestion monitoring, and system performance evaluation. The remainder of this section describes example applications of archived ITS data for transportation planning.

Example 1: Traffic Statistics and Reporting

Planners often require data at a collective level for long-range transportation. Hourly or daily summaries of volume data and hourly summaries of speed data may be required. This data is traditionally acquired through Automatic Traffic Recorders (ATR). These recorders provide an average traffic count by weekday (Monday through Friday) and weekend (Sunday through Saturday) for each month of the year. An agency in the Department of Transportation analyzes these data and produces an annual traffic report. Archived TMS data effectively queries similar data with more comprehensive spatial coverage and does not require the publication of an annual report. An automated archived data analysis system can graphically report the trend of one year's traffic speed. This is shown in Figure 6.6. The variation of system delay over a long period of time can be obtained based on TMS speed counts and the length of the road segment. Figure 6.7 shows an example of system delay variation.

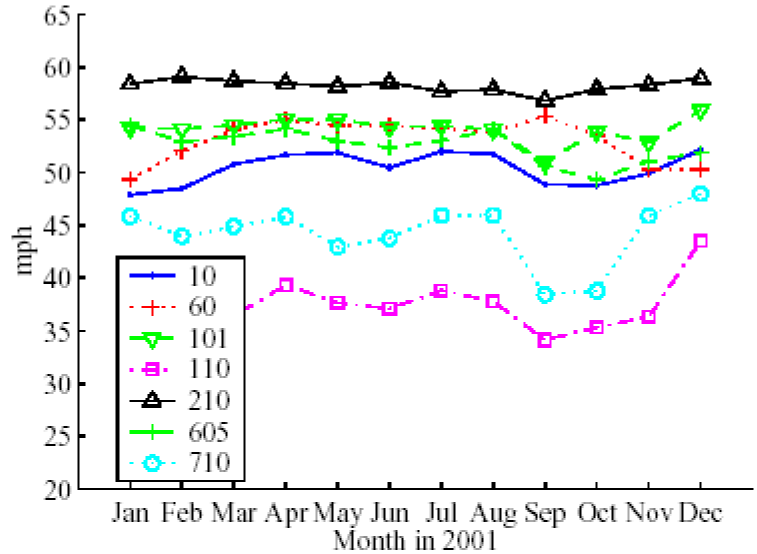


Figure 6.6 Trends of Historical Speed
Source: Pravin Varaiya, Freeway Performance Measurement System. California PATH, 2001.

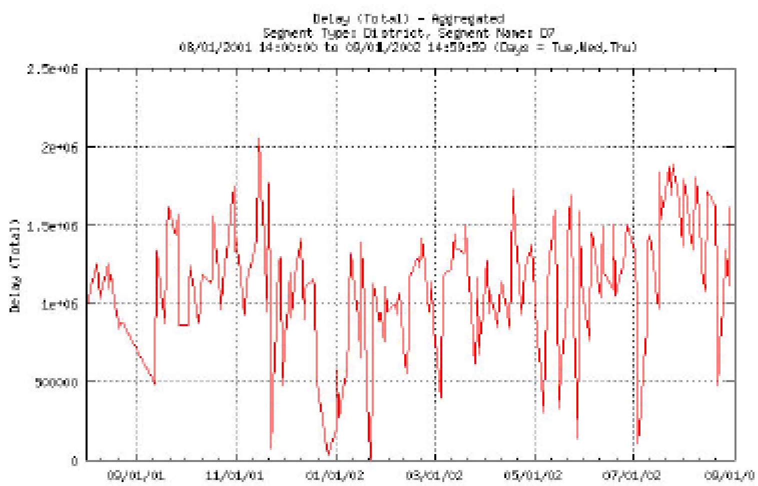


Figure 6.7 Trends of Historical Delay

Source: Pravin Varaiya, Freeway Performance Measurement System. California PATH, 2001.

Example 2: Bottleneck Analysis

Transportation planners must identify recurring congestions caused by road geometry or the lack of road capacity. TMS data facilitates the development of a contour plot of speeds along a specific road segment. The contour plot in Figure 6.8 shows a heavily congested region, marked by contours of equal speeds. Vehicles are traveling in the direction of increasing mileposts. There appears to be a bottleneck at milepost 24.

Upstream from milepost 24, speeds are low between 6:30 and 9:30 AM; downstream speeds remain high throughout the period. Figure 6.9 shows the speeds around milepost 24 at 8:00 AM where traffic flows from left to right. Here, the congested region is shown clearly between miles 14 and 24, where the speeds are below 25 mph. These two figures can be used to analyze the traffic congestion at 10600 South on southbound I-15 due to merging traffic.

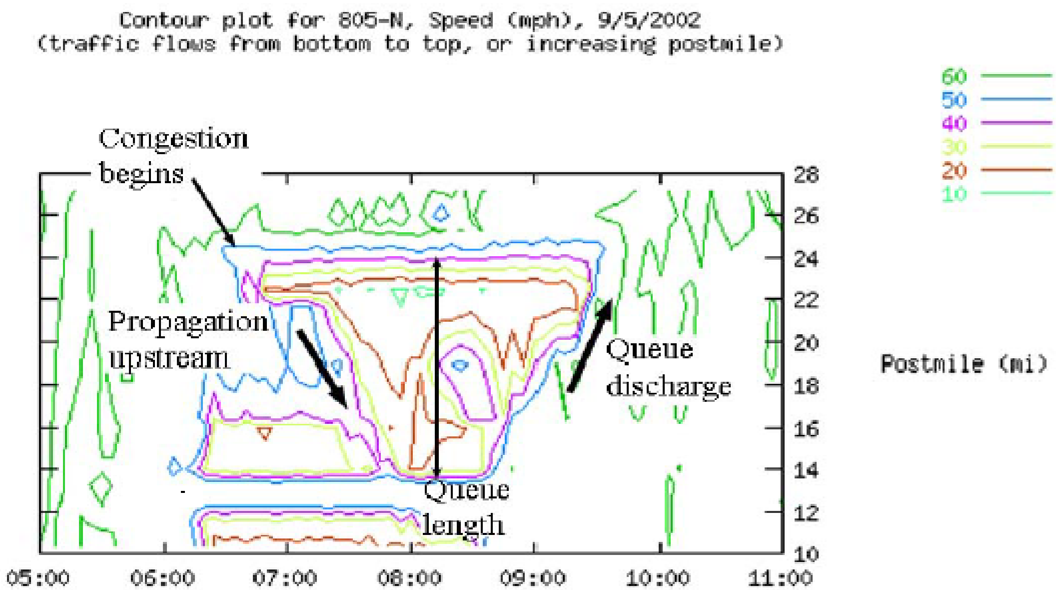


Figure 6.8 Contour Plot of Speed

Source: Pravin Varaiya, Freeway Performance Measurement System. California PATH, 2001.

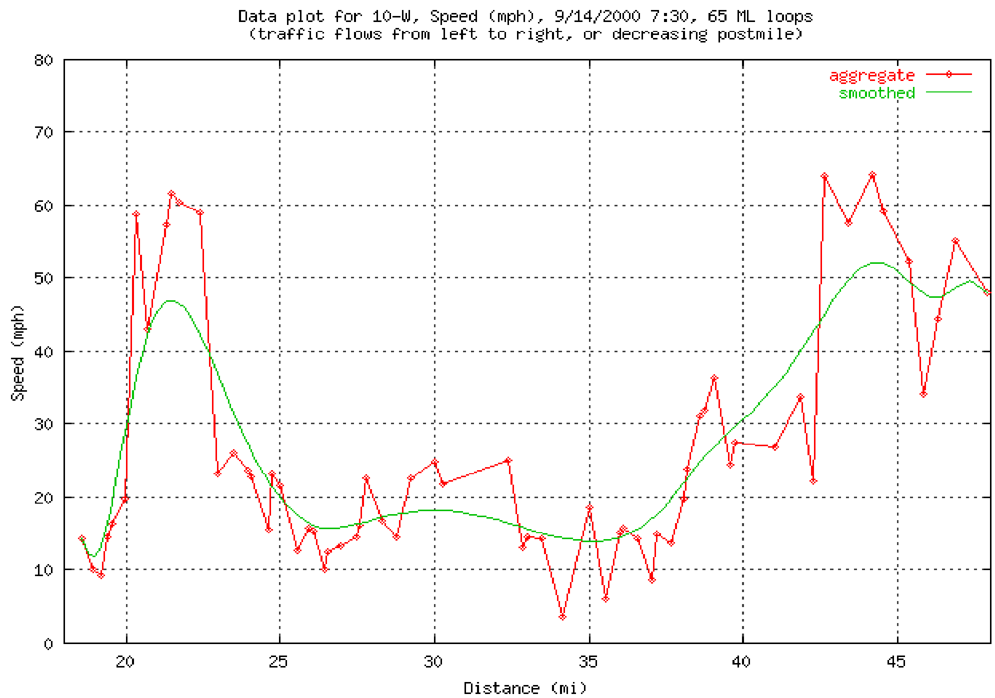


Figure 6.9 Speed Variation in Bottleneck Analysis

Source: Pravin Varaiya, Freeway Performance Measurement System. California PATH, 2001.

6.2.3 Academic Research

Transportation researchers usually desire a wide variety of data types at different temporal and spatial levels because their research is likely concerned with all aspects of transportation. This particular approach to modeling transportation problems has been partially restricted in the past due to the lack of data under various traffic conditions. Therefore, the availability and variability of archived ITS data might lead researchers to develop and test new models based upon new data resources. For example, Figure 6.10 shows how relationships can be found between speed and flow data for traffic flow theory. This picture could be acquired under any particular traffic conditions due to the comprehensive nature of ITS data.

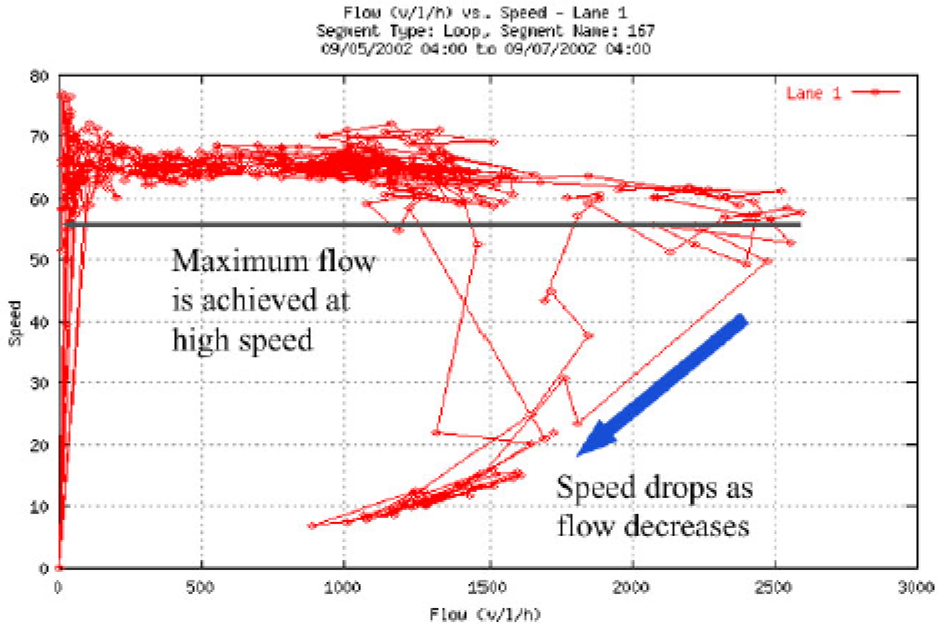


Figure 6.10 Speed versus Flow
Source: Pravin Varaiya, Freeway Performance Measurement System. California PATH, 2001.

CONCLUSIONS AND RECOMMENDATIONS

Permanent count stations and manual data collection are traditional methods for measuring transportation performance. These data sources are unreliable because of their limited spatial and temporal coverage and variability in traffic conditions. Consistent and continuous ITS data can be used in traffic operation and management, transportation planning, and academic research.

A set of models was developed using TMS data to compute basic performance measures of VMT and VHT, travel time, and delay. Some measures, such as TTI and travel time variability and reliability were also defined to provide an in-depth analysis of system performance. These measures could be at either a site-specific level or a system-wide level. They evaluate the effectiveness of the current ATMS and provide answers to transportation system problems.

Successful use of ITS data depends on the implementation of an automated data collecting, archiving and analyzing system. This study provides general guidance on how to develop such a system. It suggests that historical ITS data be kept on-line for convenient data analysis. The data quality control procedure should also be included to ensure a reliable database. A web-based user interface should disseminate information to make this system more widely accessible.

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